PMLevyCOLPEm Resource

From: Anderson, Brian
Sent: Monday, February 28, 2011 5:11 PM
To: PMLevyCOLPEm Resource
Subject: Meeting Summary - February 25, 2011 - Progress Energy Florida - Levy County Units 1 and 2 COLA - Tsunami Flooding Review and Draft RAI # 5528 related to SRP Section 2.4.6
Attachments: LNP tsunami flooding review.pdf

Importance: High

MEMORANDUM TO: File (Docket Numbers 52-029, 52-030, Levy County Units 1 and 2 COLA)

FROM: Brian Anderson
Office of New Reactors, Division of New Reactor Licensing
Senior Project Manager, AP1000 Projects Branch 1

SUBJECT: Summary of Meeting with Applicant on February 25, 2011

On February 25, 2011, NRC staff participated in a category 1 public meeting with Progress Energy Florida, Inc. (PEF) representatives (see list below) regarding the staff's detailed review of the Levy County Units 1 and 2 COLA. The purpose of the meeting was to discuss the staff's tsunami flooding review and associated draft RAI (electronic-RAI (e-RAI) ID # 5528). PEF was provided a draft copy of e-RAI # 5528 via e-mail on February 14, 2011.

The meeting focused on equations used by PEF to describe the generation, attenuation, shoaling, beaching, and run-up for a probable maximum tsunami at the proposed Levy County site. During the meeting, discussion centered on how the theoretical assumptions used in PEF's FSAR section 2.4.6 were applicable and conservative for the proposed Levy County site. PEF's presentation slides are attached to this meeting summary.

At the conclusion of the meeting, the NRC staff informed PEF that e-RAI # 5528 would be issued without changes.

The NRC attendees were:
Brian Anderson
Doug Bruner
Henry Jones
Pat Lynett
Tom Galletta
Jason Caytor

PEF (applicant) attendees were:
Bob Kitchen
Dave Waters
Paul Snead
Mitch Griffin
Bryan Burkingstock
Steven Ward

Hearing Identifier: Levy_County_COL_Public
Email Number: 777

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Florida Tsunami Flooding Review of the Levy County Units 1 and 2 COLA

NRC Category 1 Meeting
Friday, February 25, 2011
10:00 a.m. – 12:30 p.m.

Progress Energy

RAI 5528 - Hydrology

- Bob Kitchen – PEF, Manager Nuclear Plant Licensing
  - Introductions
  - Meeting Purpose
- Dr. Mitch Griffin – CH2M HILL, Principal Technologist
- Dr. Steven Ward – University of California, Santa Cruz
- Paul Snead – PEF, Environmental Supervisor
- Bryan Burkingstock – CH2M HILL, Task Manager
- Dave Waters – PEF, Lead Licensing Engineer

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Presentation Focus

- Theoretical assumptions relevant to propagation equations for
  - Landslide-generated wave
  - Run-up/inundation
- Justify why the Ward equations are applicable and conservative for the site.
- Theoretical assumptions behind equations for:
  - Generation
  - Attenuation
  - Shoaling
  - Beaching
  - Run-up
- Justify why assumptions are valid and conservative for the site.

Commonly Used Acronyms and Abbreviations

- PEF – Progress Energy Florida
- COLA – Combined License Application
- LNP – proposed Levy Nuclear Plant Units 1 & 2
- FSAR – Final Safety Analysis Report
- PMT – Probable Maximum Tsunami

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LNP Site Location - Florida

LNP Site

- 7.9 miles east of Gulf of Mexico
- 3 miles north of Lake Rousseau
- Plant Design Grade Elevation = 51 ft. NAVD88

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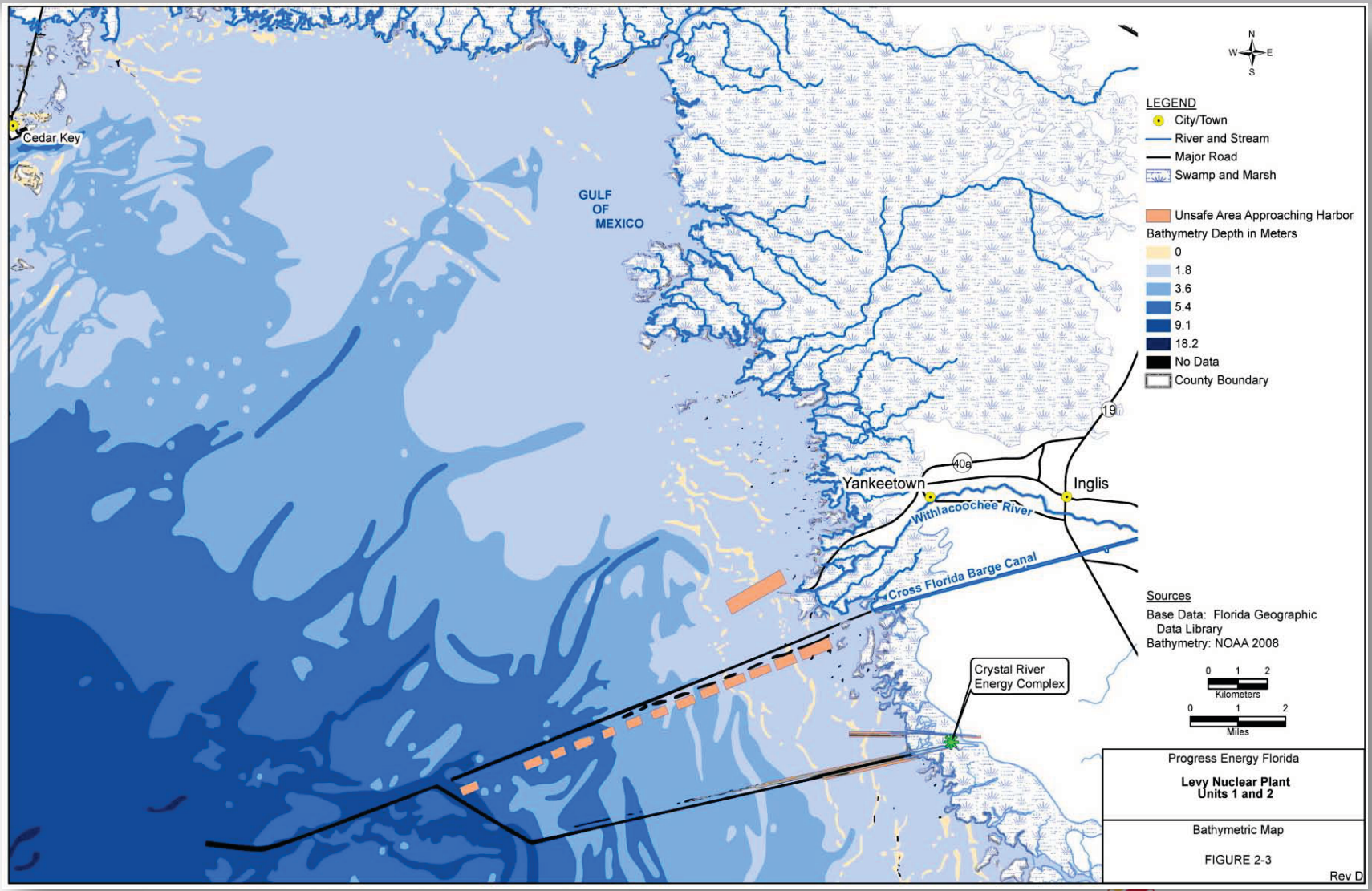
LNP Nearshore Conditions



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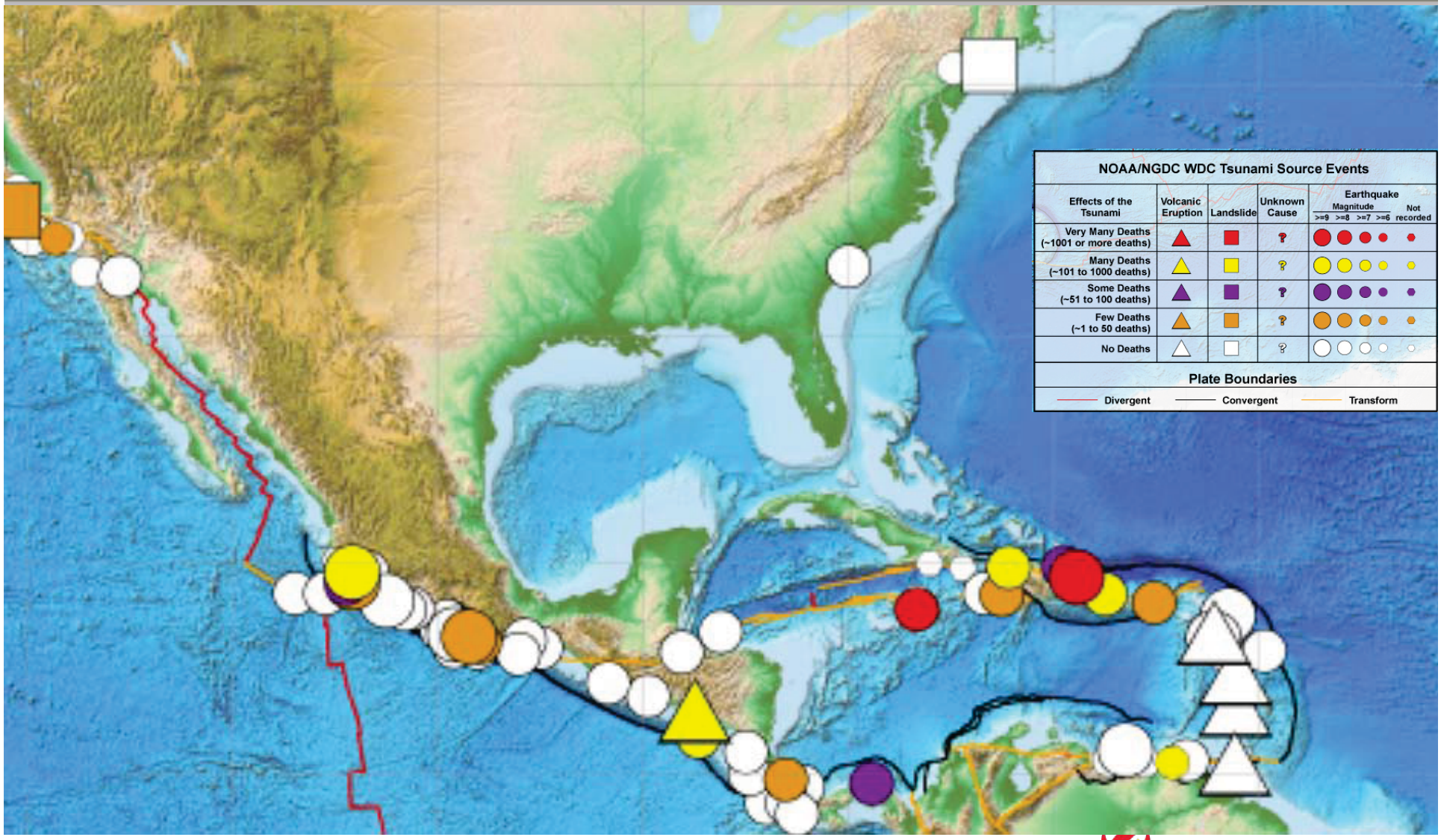
Tsunami Sources from 1650 B.C. to A.D. 2010 from Earthquake, Volcano, Landslide, and Other Causes.

International Tsunami Information Center. itic.ioc-unesco.org Accessed Feb. 17, 2011.



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NRC Definition of the PMT

From "Tsunami Hazard Assessment at Nuclear Power Plant Sites in the United States of America", published March 2009:

PMT is that tsunami for which the impact at the site is derived from the use of best available scientific information to arrive at a set of scenarios reasonably expected to affect the nuclear power plant site, taking into account (1) appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated; (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena; and (3) the importance of the safety functions to be performed.

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PMT Initial Efforts Made by PEF

- Because of low PMT potential, the following approach was used in LNP FSAR, Rev. 0:
  - Comprehensive literature review was conducted that included: sources (seismic and landslide), generation, propagation, and run-up.
  - Based on an extensive literature search and site-specific borings at LNP, no geologic evidence of paleo-tsunami or tsunami-like deposits or geologically conducive locations for deposition were found in the vicinity of the Levy County site or in nearby regions.
  - Additionally, several hypothetical but plausible earthquake and landslide PMTs were presented based on the available literature and predicted tsunami water levels.

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PMT Modeling Efforts Made by PEF

- A more refined assessment was required to address specific RAI requests.

- This approach explicitly estimates each step of tsunami wave propagation: source amplitude, propagation loss, shoaling correction, beaching amplification, and inundation distance/height.

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Presentation Request:
4th Paragraph of the Draft 02.04.06 RAI

- If the applicant chooses to use an approach which relies on the Ward, et al. publication[s], the applicant is requested to provide a complete presentation of the theoretical assumptions that are relevant to propagation equations for a landslide-generated wave and run-up/inundation.
- In addition, the applicant is requested to provide site-specific justification as to why the Ward equations are applicable and conservative for the proposed Levy County site.
- This discussion should include a presentation of the theoretical assumptions behind the generation, attenuation, shoaling, and run-up equations, and a justification of why these assumptions are valid and conservative with respect to site-specific conditions.

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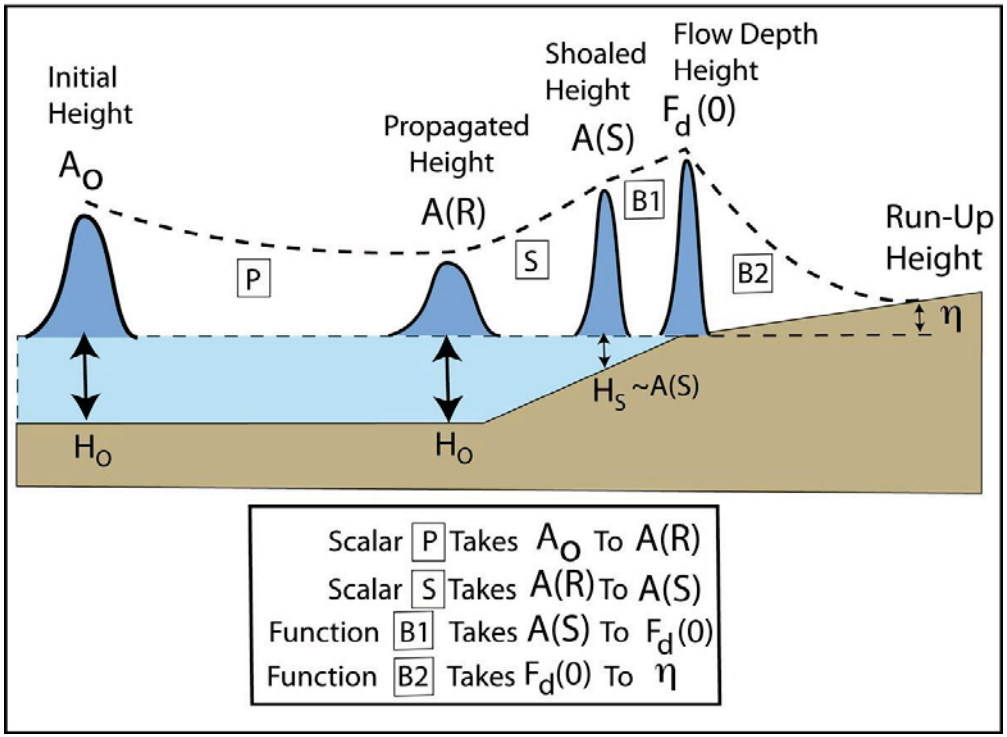
Tsunami Prediction Using Formulae-Based Approach Developed by Ward, et al.

The essence of the PMT calculation is detailed in this chart. This presentation will provide the "step by step" process used by Progress Energy to calculate the PMT for the LNP site.

Run Up Flow Chart



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Whether by full numerical simulation OR by a formulaic approach, tsunami wave height computations involve five steps:

- 1. Generation, A_0
  - Landslide
  - Earthquake
- 2. Propagation across deep water, A(R)
- 3. Shoaling into shallow water, A(S)
- 4. Beaching to shore, h or $F_d(X_0)$
- 5. Run-up on land, η or $T(X_{max})$

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PMT Analysis Efforts Made by PEF

- The formulae-based approach was selected to conduct a bounding analysis for each step (formula are based on the results of numerical modeling).
  - Each step has conservatism included by nature of the bounding equation(s). Each step can be quantified.
  - There is no universally accepted numerical model for tsunamis. Numerical modeling includes the steps implicitly; all programs have some assumptions within its framework.
- PEF conducted a comprehensive literature review of both peer-reviewed articles and books and found Dr. Ward's numerical modeling had been used to analyze most historical tsunamis, and with good results. With Dr. Ward's assistance, the formulaic approach was developed for the LNP site.

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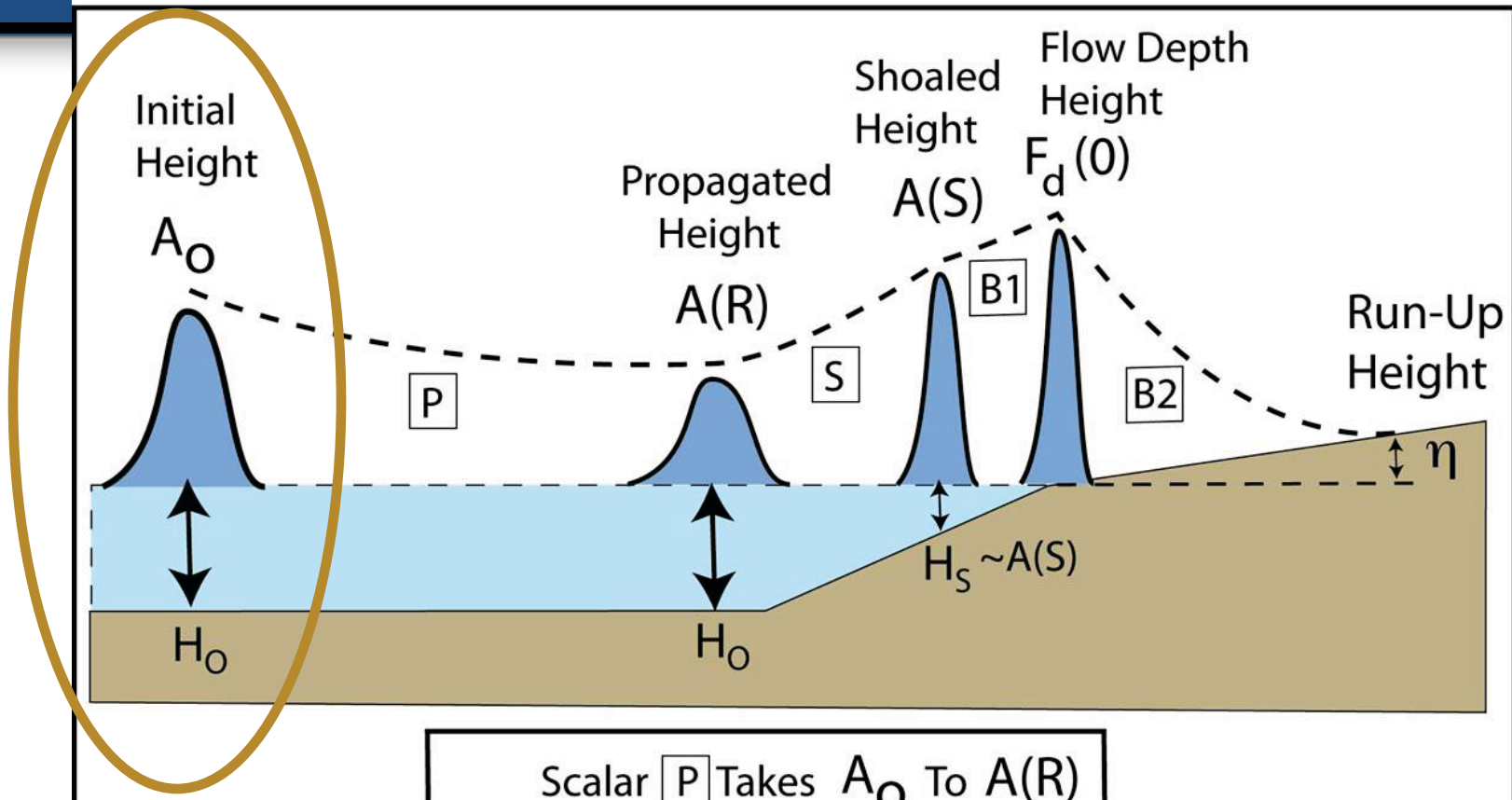
Run Up Flow Chart



Scalar	P	Takes	A_O	To	A(R)
Scalar	S	Takes	A(R)	To	A(S)
Function	B1	Takes	A(S)	To	$F_d(0)$
Function	B2	Takes	$F_d(0)$	To	η

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Step 1. Tsunami Generation

- Earthquakes or Landslides produce tsunami waves with radiation patterns. That is, tsunami are bigger in some directions than others.
- A_0 is defined to be the LARGEST amplitude in any direction.

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1. Tsunami Generation Factors

- Specifically, A_0 is the initial peak tsunami wave amplitude in any direction.
  - Most landslide tsunamis studied here are pointed away from LNP, so this adds conservatism by using the peak.
  - For earthquake tsunamis A_0 conservatively equals the maximum uplift.
- A_0 equals the thickness of a landslide times a factor that depends on slide speed.
  - Faster slides generate bigger waves.
  - Equation 2.4.6-3 (all equations refer to FSAR, RAI-16):

$$A_0 = 3.5T\left(\frac{V_s}{\sqrt{gH_0}}\right)^{1.8}$$

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1. Tsunami Generation Factors (cont.)

- A_0 equation for landslides was fitted to simulation results. Reference: *Steven N. Ward, Landslide Tsunamis, Journal of Geophysical Research, Vol.106, No. B6, pp.11201-11215, 2001*.

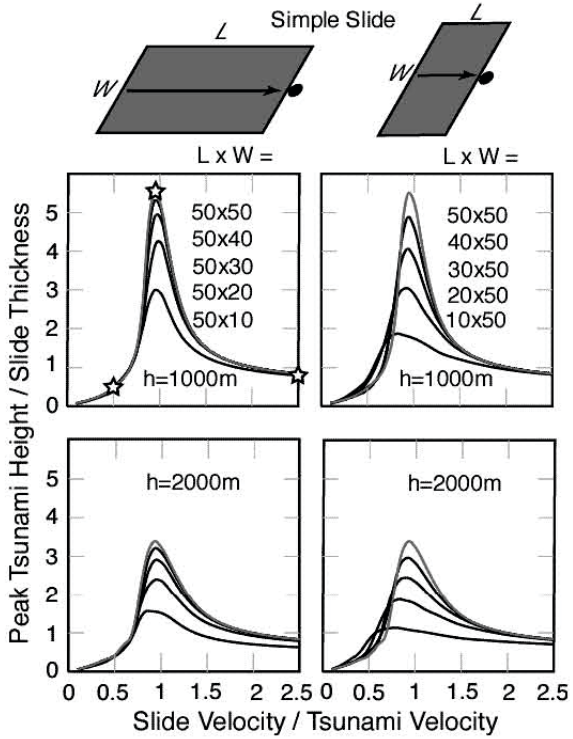

Figure 3. Effects of slide velocity, slide dimension and water depth on peak tsunami height. Slides that happen too fast (right sides of boxes) or too slow (left sides of boxes) are inefficient generators of tsunami. The stars in the top left panel indicate the conditions in top, middle and bottom cases of Figure 2.

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1. LNP Specific Data: Landslide Sources

- H_0 from bathymetry data (NOAA)
- Velocity of Landslides
  - Range used to bracket possible speeds: 25 m/s and 50 m/s.
  - Slopes are not very great in Gulf of Mexico (e.g., <1° Mississippi Canyon region).
- Location, area, thickness and volume of slides were based upon data provided in the document, *USGS 2008. "Evaluation of Tsunami Sources with the Potential to Impact the U.S. Atlantic and Gulf Coasts," which is an updated report to the Nuclear Regulatory Commission by the Atlantic and Gulf of Mexico Tsunami Hazard Assessment Group (pages 36 and 37)*.

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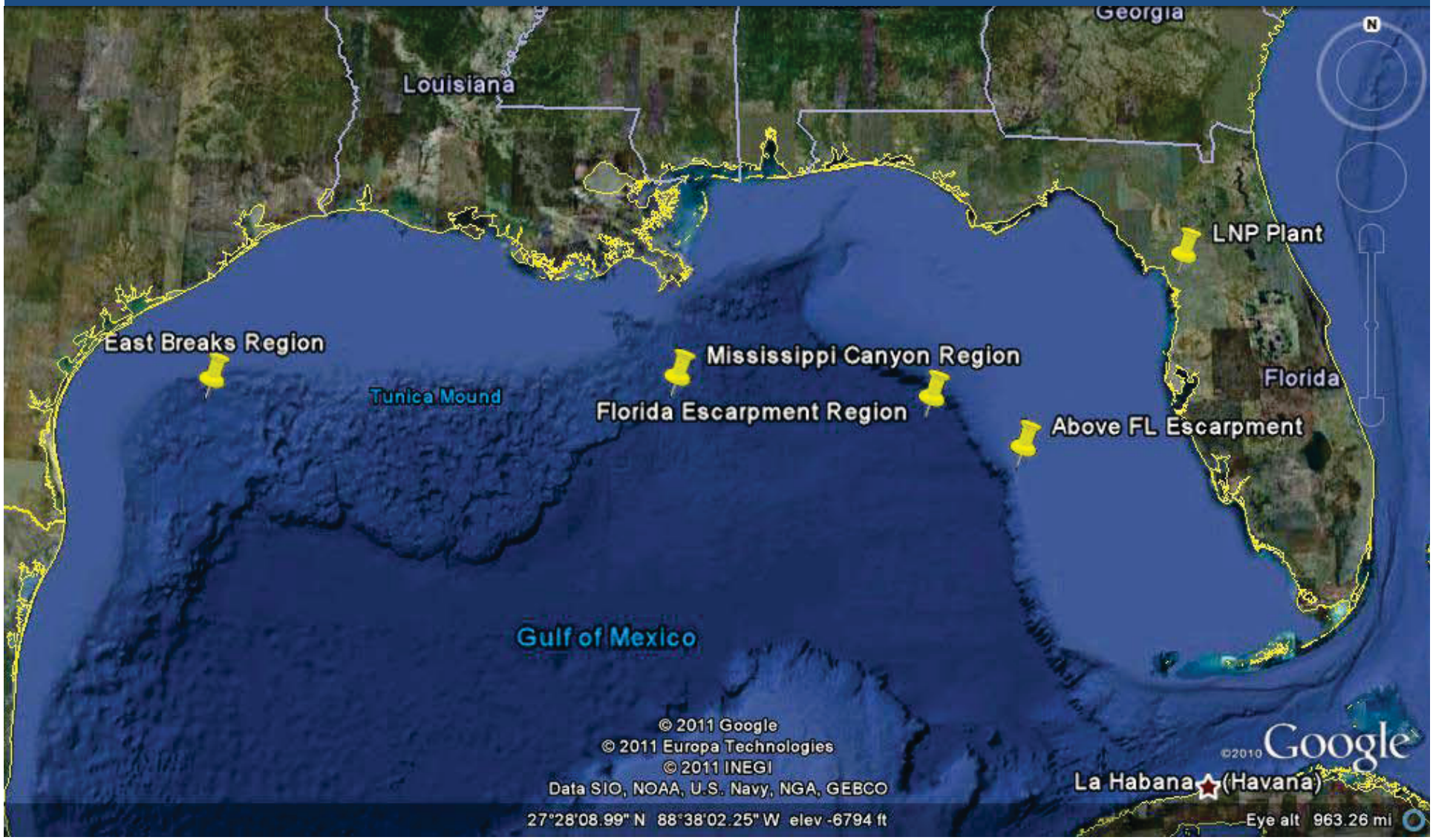
Three Main Sources for Landslides



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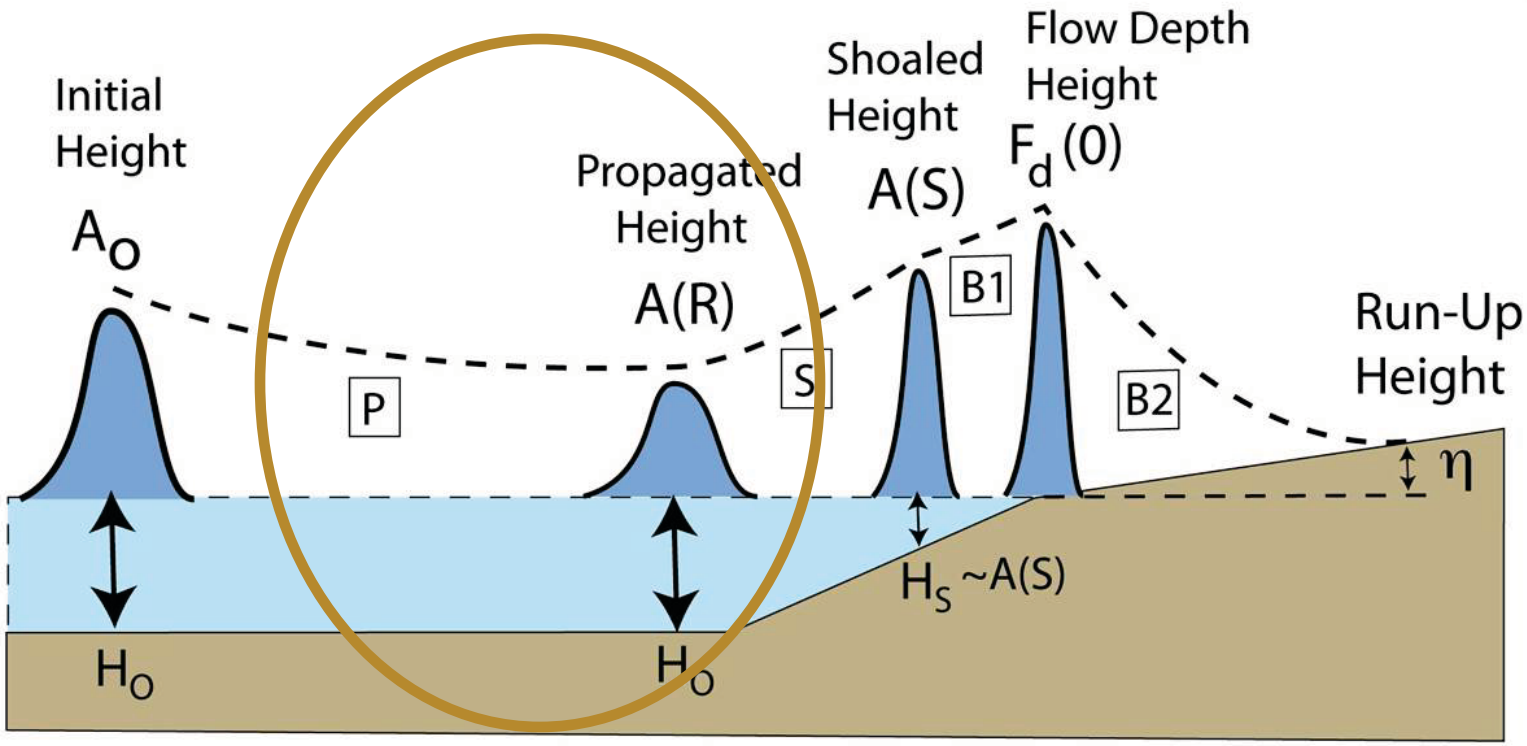
Run Up Flow Chart



Scalar	P	Takes	A_O	To	A(R)
Scalar	S	Takes	A(R)	To	A(S)
Function	B1	Takes	A(S)	To	$F_d(0)$
Function	B2	Takes	$F_d(0)$	To	η

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Step 2. Tsunami Propagation From Source to Shallower Water

- Waves get SMALLER as they spread out from source by dispersion.
- The propagation factor "P" modifies the initial peak wave amplitude (A_0) to determine the propagated height, A(R), or the wave amplitude at distance R from the source.
- Waves decay proportional to:

1/sqrt(distance) > P > 1/distance

Distance is from the source toward the site, R.

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2. Tsunami Propagation Theory

- Specifically, Equations 2.4.6-8 and -9 with R being the distance from the source, D being the dimension of the source, and H_0 being the water depth at the source:

$$P = \left(1 + \frac{2R}{D}\right)^{-\left[0.5 + 0.575 \exp\left(-0.0175 \frac{D}{H_0}\right)\right]}$$

- P is independent of A_0 but dependent on the ratio of D/H_0. Smaller sources (i.e., lower D/H_0) yields lower P because of DISPERSION is less for smaller events.
- $P < 1$, so wave size at distance is less than the initial amplitude $A(R)<A_0$.

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2. Tsunami Propagation Theory (cont.)

- Equation 2.4.6-11 for landslides:

$$A(R) = A_0 P$$

$$A(R) = 3.5T \left(\frac{V_s}{\sqrt{gH_0}} \right)^{1.8} \left(1 + \frac{2R}{D} \right)^{-\left[0.5 + 0.575 \exp\left(-0.0175 \frac{D}{H_0} \right) \right]}$$

- Initial reference: *Ward, S. N., and Asphaug, E. (2002). Asteroid Impact Tsunami of 2880 March 16. Geophysics. J. Int., 153. p 6-10*.
  - The values 0.575 and -0.0175 in P were fitted to many full-scale numerical simulations. The value 0.5 is the sqrt(distance) loss due to GEOMETRICAL SPREADING.

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2. LNP Specific Data: Propagation

- R is the distance in kilometers from:
  - End of landslide.
  - Source of earthquake.
- D is the dimension of the disturbance:
  - Estimated as the diameter of the area of disturbance from the following massive slides:

Potential Landslide Considered	Volume (Km^3)	Area (Km^2)
East Breaks	520	22
Mississippi Canyon	3,720	428
Florida Escarpment	648	16.2
Slope above the Florida Escarpment	648	16.2

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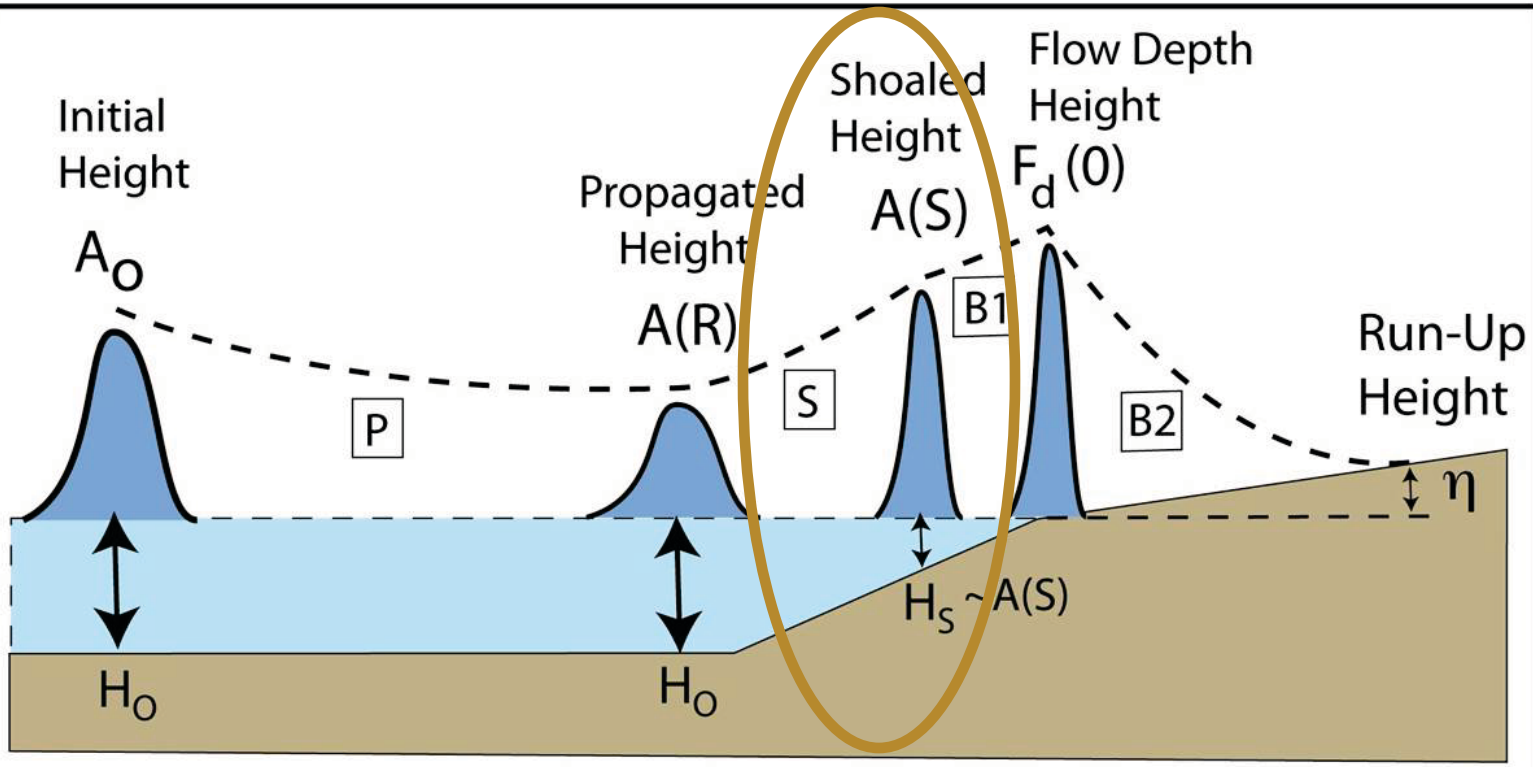
Run Up Flow Chart



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Step 3. Tsunami Shoaling

- Tsunami waves slow and GROW as they move into shallower water because their wave energy gets compressed vertically and horizontally. This effect is called shoaling.
- The deep water propagated height A(R) is adjusted to transfer the wave to shallow water at a depth about equal to the wave height.
- The result is called the <u>shoaled wave height</u>, A(S).

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3. Tsunami Shoaling Theory

- Shoaling factor "S" > 1 and takes A(R) to A(S) by Equation 2.4.6-13:

$$A(S) = A(R)\,S = A(R)\left(\frac{H_0}{H_s}\right)^{1/4}$$

- S above is conservative because:
  - (1) it is the largest correction applicable to long waves. Shorter dispersive waves would actually grow less.
  - (2) No additional frictional losses are included in moving across the continental shelf into shallow water.
- Reference: *Chesley, S. R., and Ward. S. N. (2006). "A quantitative assessment of the human and economic hazard from impact-generated tsunami." Natural Hazards, 38: 355-374*.

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3. LNP Specific Data: Shoaling

- H_0 is already defined as the water depth in the source region.
- So what is H_s?
  - H_s is not used in the final calculation as it cancels out (see next step).
  - H_s is included to illustrate the “step-by-step” nature of tsunami transformation from source to site.

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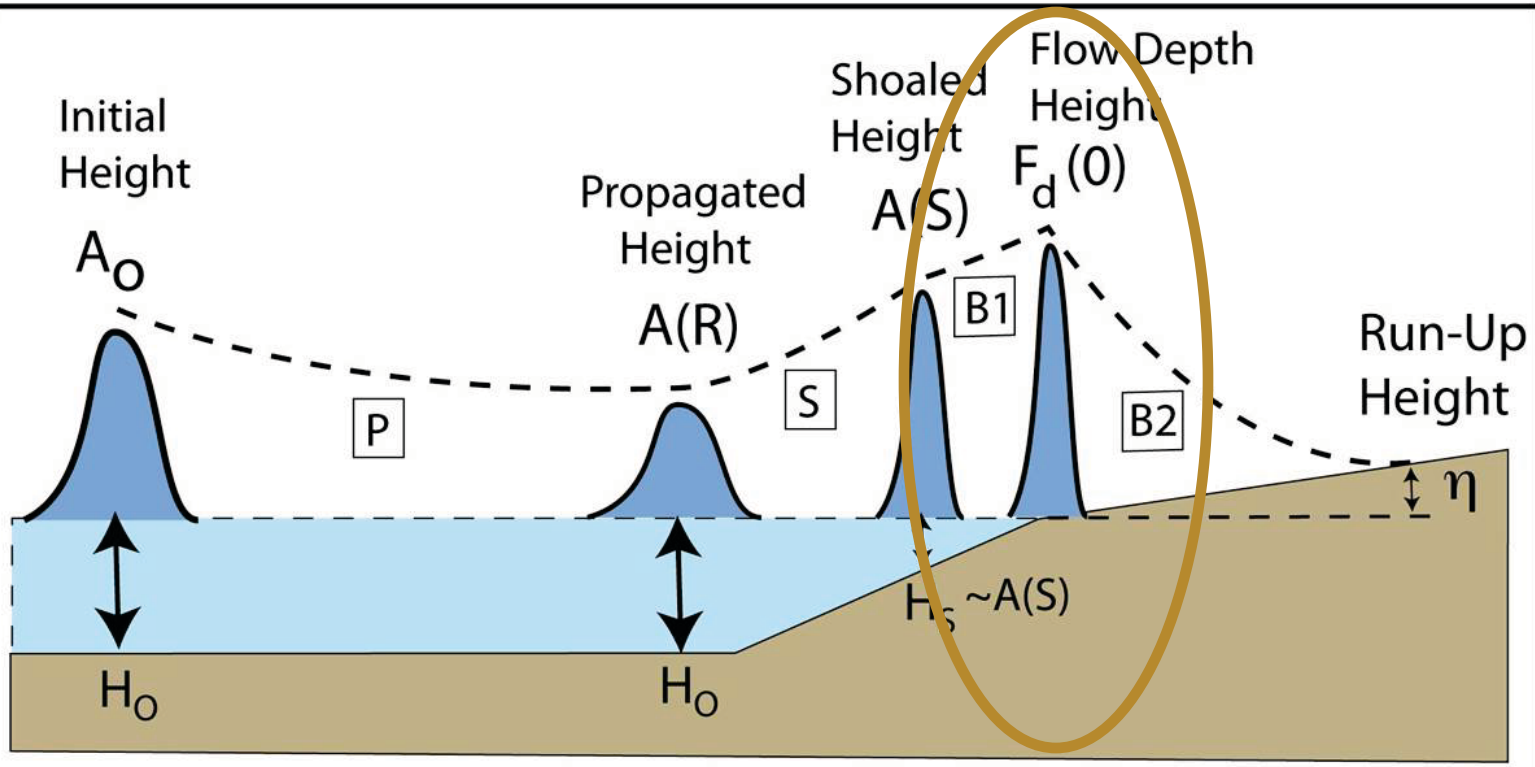
Run Up Flow Chart



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Function	B1	Takes	A(S)	To	$F_d(0)$
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Step 4. Tsunami Beaching

- Tsunami can't get bigger and bigger forever as they move into shallower and shallower water. Eventually they reach a terminal size and possibly break in a process called BEACHING.
- Beaching is a complex, non-linear process that depends on beach slope, wave size, and period; however, it can be generalized in a fairly simple way.
- Beaching function "B1" takes shoaled height A(S) to $F_d(0)$, the flow depth at the beach.
  - $F_d(0)$ is also called *h* in the FSAR to match terminology requested in LNP RAI 02.04.06-16.

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4. Tsunami Beaching Theory

- Equation 2.4.15 Reference: *Chesley, S. R., and Ward. S. N. (2006). "A quantitative assessment of the human and economic hazard from impact-generated tsunami." Natural Hazards, 38: 355-374*.

$$F_d(0) = h = A(S)^{4/5} H_S^{1/5}$$

- Plug A(S) = A(R)S into above equation and reduce the terms to yield Equation 2.4-16:

$$F_d(0) = h = A(R)^{4/5} H_0^{1/5}$$

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4. Tsunami Beaching Theory (cont.)

- Notes:

$$h = A(R)^{4/5} H_0^{1/5} = F_d(X_0)$$

  - $F_d(X_0)$ is flow depth at the beginning of the run-in/run-up computation.

- Switch to land based dimensions, X, for final phase. X is the distance in from the beach, F(X) is depth of wave at X.
  - X_0=0 is where run-in computation begins at shoreline.
  - X_0>0 is where sea level rises from climate change.

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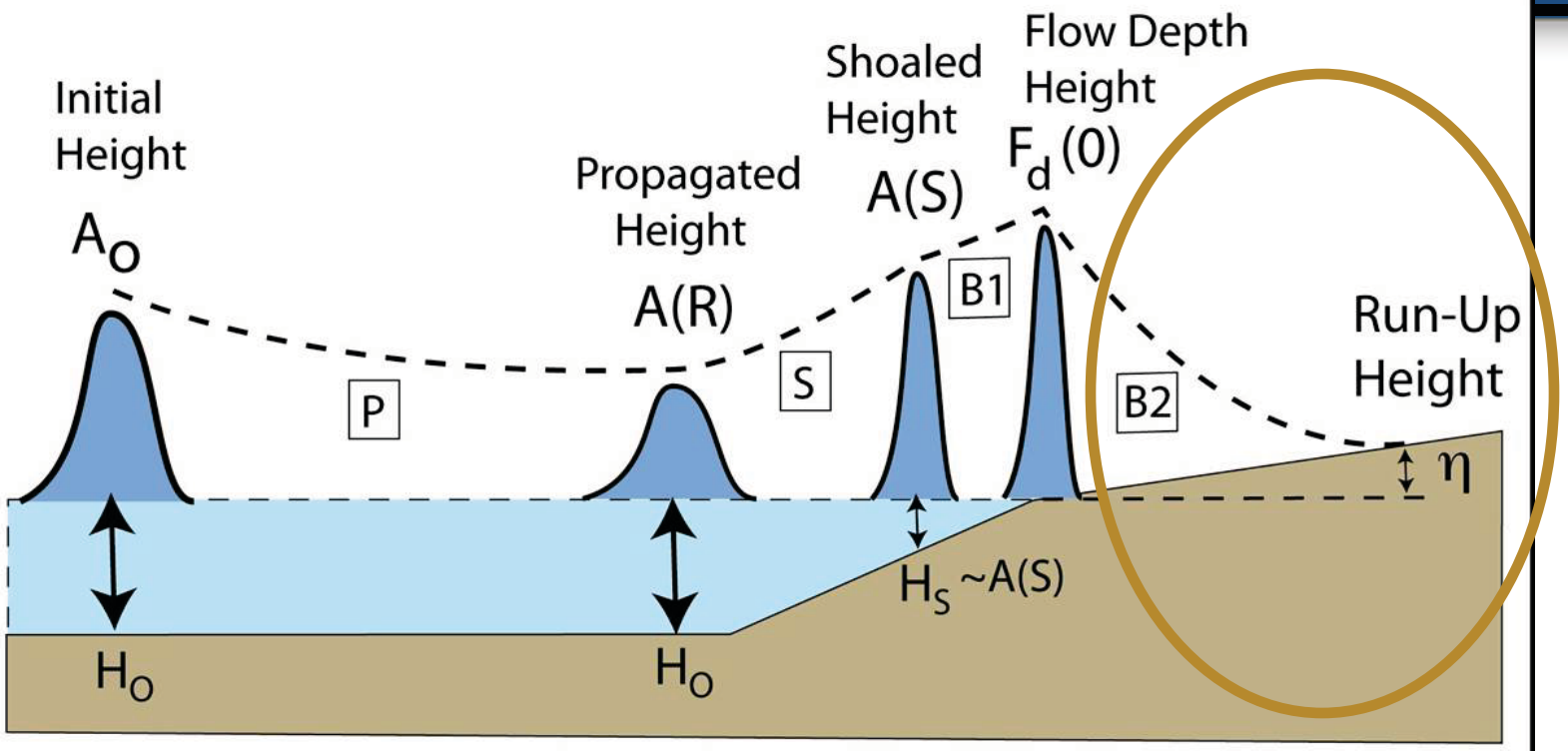
4. LNP Specific Data: Beaching

- Beaching step is not really a site-specific phenomenon when the bounding formula is applied.
  - H_s cancels out.
  - All terms are previously defined.

Run Up Flow Chart



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Function	B1	Takes	A(S)	To	$F_d(0)$
Function	B2	Takes	$F_d(0)$	To	η

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Step 5. Tsunami Run-up

- When the wave starts to run over dry land, FRICTION acts to make the flow and wave SMALLER.
  - Eventually there is no flow left and the wave gets turned back. The elevation at this location is called the “run-up height,” or just the run-up.

- Run-up is the terminus elevation; Run-in is the distance the wave travels inland. Literature uses both terms.

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5. Tsunami Run-up Theory

- Run-in formula "B2" takes the flow depth at the shoreline $F_d(0)$ to run-up height at X_{max}.
- Equation 2.4.6-17 is the starting equation:

$$X_{\max} = F_d(0)^{1.33} / (16.7 n^2)$$

  - n is "Manning's Coefficient". It specifies the frictional resistance to the flow. A higher "n" means less inundation.

- References: *Gerardi. F., Barbano, M. s., De Martini, P. M., and Pantosti, P. (2008). Discrimination of Tsunami Sources (Earthquake versus Landslide) on the Basis of Historical Data in Eastern Sicily and Southern Calabria, Bulletin of the Seismological Society of America; December 2008; Vol. 98; no. 6; p. 2795-2805.*

  Institute of Geological & Nuclear Sciences. [IGNS] (2005). Review of Tsunami Hazard and Risk in New Zealand. http://www.civildefence.govt.nz/memwebsite.nsf/wpg_URL/For-the-CDEM-Sector-Publications-Tsunami-Risk-and-Preparedness-in-New-Zealand?OpenDocument. Accessed November 9, 2010.

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5. Tsunami Run-up Theory (cont.)

- Equation 2.4.6-17 was modified to take site-specific topography into account, Equation 2.4.6-18:

$$\frac{dF_d(X)}{dX} = -\left[\frac{16.7n^2}{F_d(0)^{0.33}} + \frac{dT(X)}{dX}\right]$$

  - T(X) is the topographic elevation in meters.
  - $F_d(X)$ is the flow depth in meter at inland position X.
- Flow depth decays faster with X as n (friction) gets larger.

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5. LNP Specific Data: Run-up

- Given $F_d(X_0)$ the flow depth at the beach (we have this from Step 4), the equation above establishes both X_{max} and η.
- Run-in function "B2" is very site-specific as it depends on flow friction at the site (grass, trees, urbanized, etc.) and the site topography from the beach to the site.
  - Assumed n = 0.03, about same as built-up urban land. Land is actually mostly forested (could have used n = 0.07).
  - Used actual profile of landscape.

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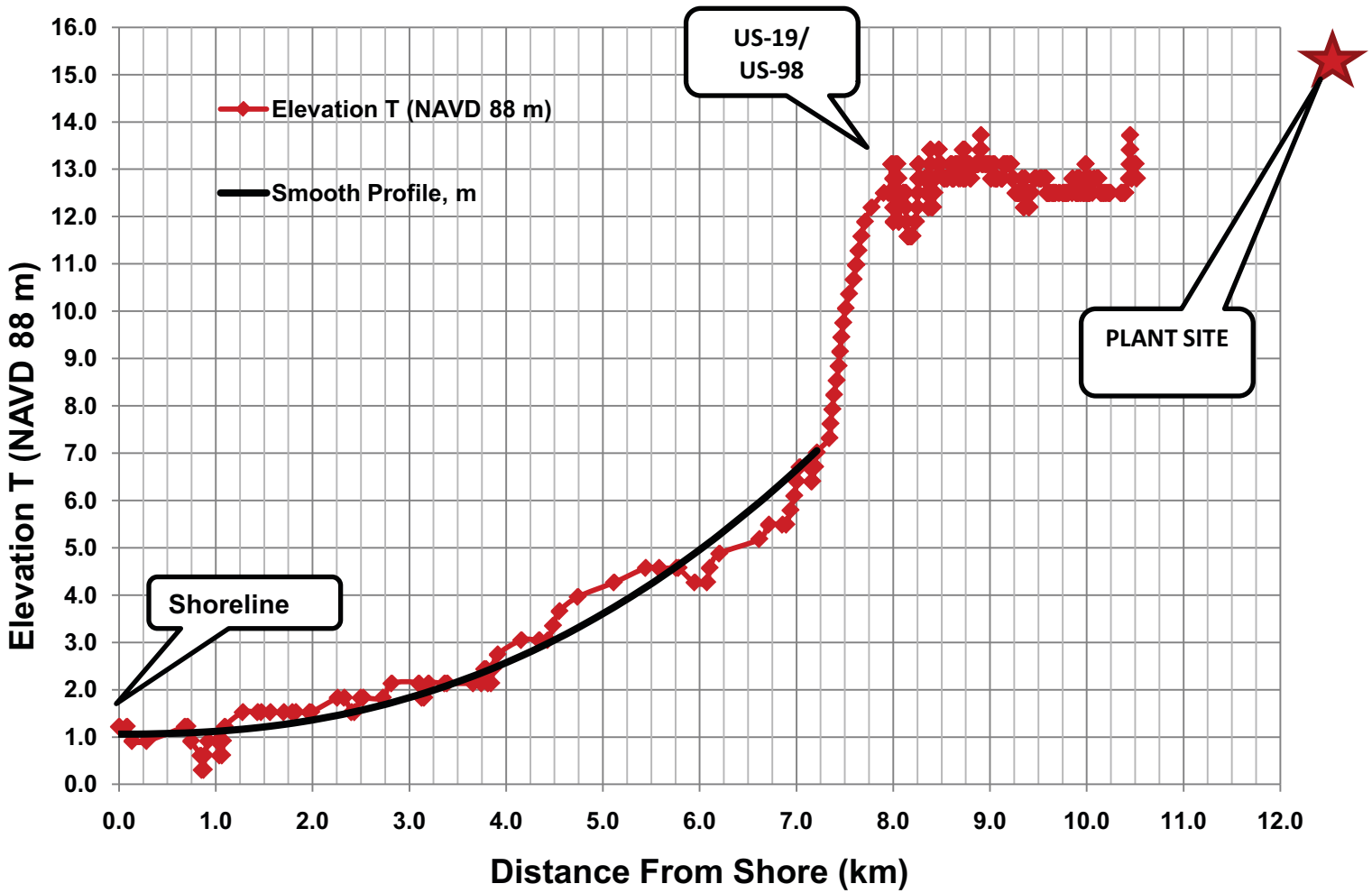
5. Landscape Profile between the LNP site and the Gulf of Mexico



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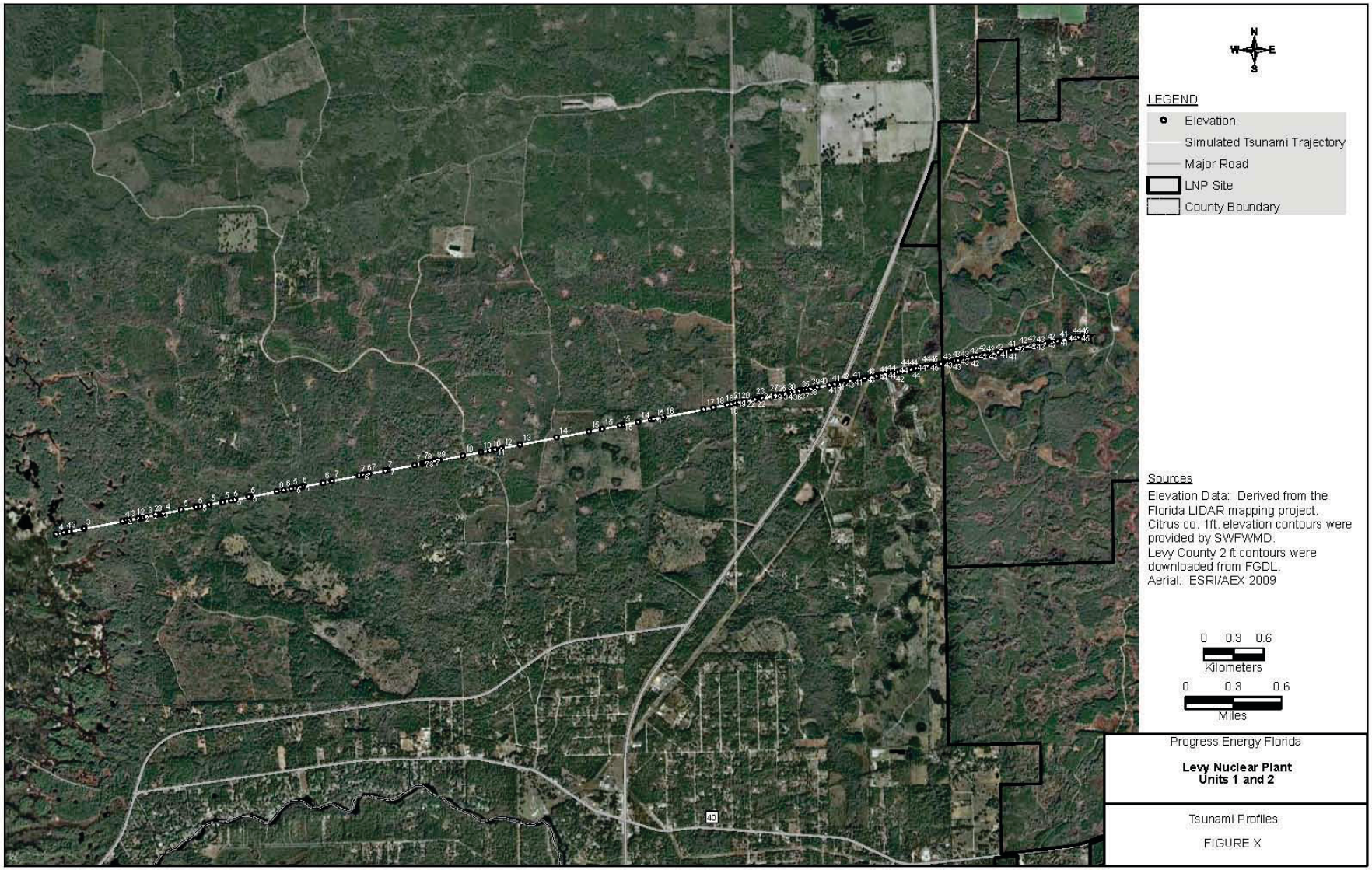

Note: US-19/US-98 is at EL 41 ft.(12.5 m) and LNP is at EL 51 ft. (15.2 m) NAVD88. US-19/US-98 is a barrier if the tsunami reached that elevation and distance inland.

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5. Tsunami Run-up Theory (cont.)

- Recipe for "B2" from Equation 2.4.6-20:

$$[T(X_{\max}) - T(X_0)] + \frac{16.7n^2}{F_d(X_0)^{0.33}}(X_{\max} - X_0) = F_d(X_0)$$

- Using T(X) from the site-specific profile and known $F_d(X_0)$:
  - Start at the shoreline, $X_{max} = X_0 = 0$, and step inland increasing X_{max}.
  - When the left-hand-side of the equation equals the right-hand-side, the resulting X_{max} is the run-in distance and $T(X_{max})$ is the run-up height.

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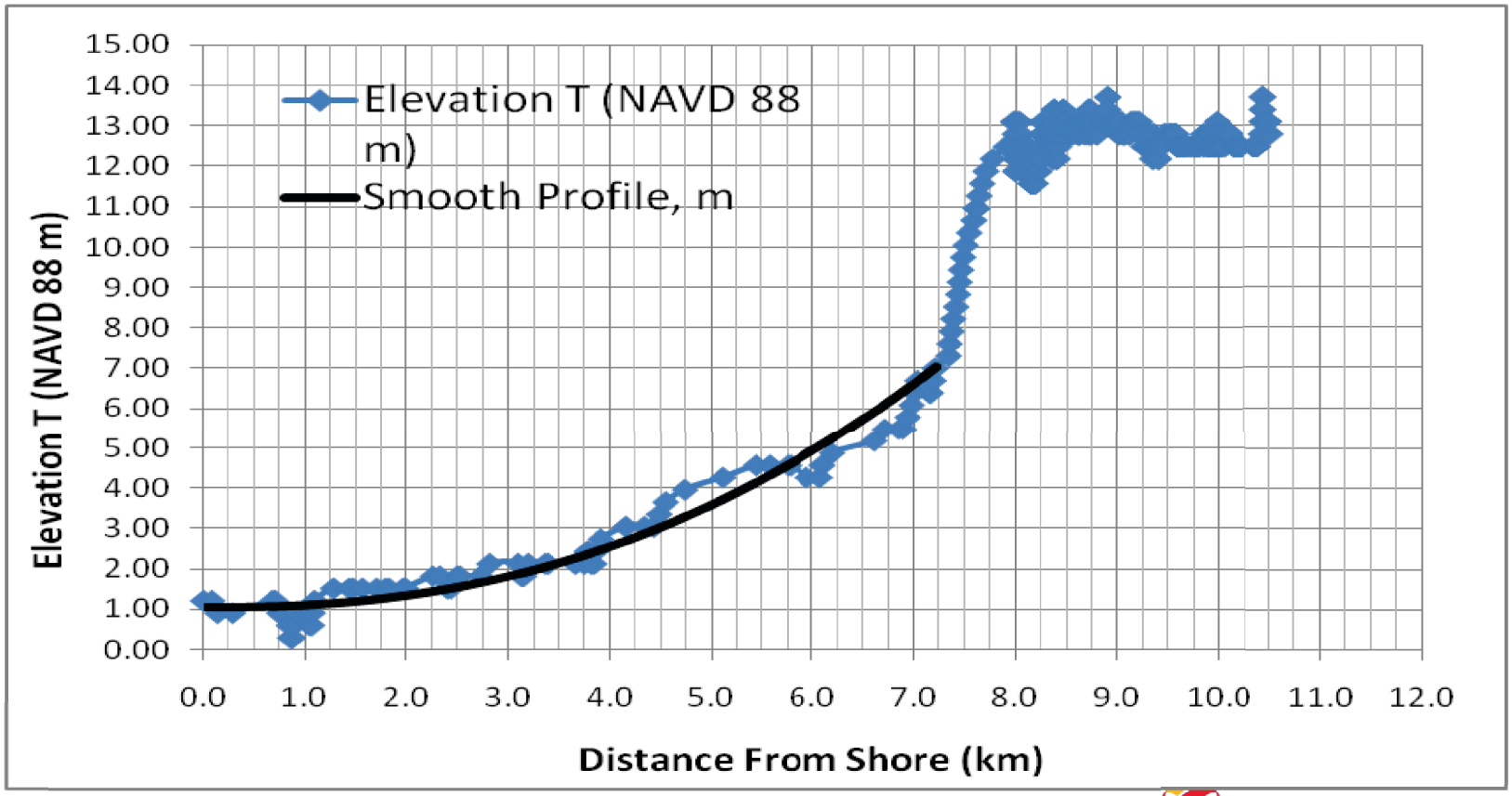
5. Tsunami Run-up Theory (cont.)

- You can use actual topographic profile, or a function fit to the profile like….

$$T(X) \approx a + bX^c$$



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Landslide PMT Results

LNP Probable Maximum Tsunami

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Landslide Results

- Landslide results using normal sea level conditions:
  - Run-up ranged from 1.06 to 2.30 m, or EL 7.5 ft. NAVD88 max. (Table 5, FSAR, RAI-16).
  - The Mississippi Canyon analysis produced the maximum run-up prediction.
  - The maximum run-in distance is about 3.4 km from shoreline, or 9.4 km (5.8 miles) away from the LNP site.

Summary of Results (cont.)
LNP Specific Data: Worst-Case

- To add additional conservatism in the computation, the PMT analysis used the same long-term Gulf of Mexico rise as used in the Probable Maximum Hurricane computation:

Sea Level Corrections	Value	Unit
10% Exceedance High-Tide	2.68	ft NAVD88
Sea level anomaly	0.60	ft
Long-term Sea Level Rise	0.39	ft
Total adjustment	3.67	ft NAVD88
Total adjustment	1.12	m NAVD88
T(0) =	2.18	m NAVD88

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LNP PMT Worst-Case Landslide Run-up Results

- Gulf of Mexico sea level rise causes the shoreline-water boundary to shift inland.
  - Moves X_0 inland 3.52 km.
  - $T(X_0)$ changes from 1.06 m to 2.18 m.
- Mississippi Canyon (highest PMT)
  - Gulf rise changes run-up from 2.3 m to 6.1 m (i.e., 7.6 ft to 20.1 ft, EL NAVD88).
    - MUCH lower than LNP site at EL 50 ft. NAVD88.
  - Run-in changes to about 7 km from the existing shoreline, or about 5.8 km (3.6 miles) from LNP.

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Summary and Conclusions

LNP Probable Maximum Tsunami

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LNP Site is a low risk to PMT because…

- Historically, no Caribbean tsunami has resulted in significant damage to the U.S. Gulf Coast.
  - According to NOAA (GAO-06-519 U.S., *Tsunami Preparedness*), the Gulf of Mexico is a low hazard area for both distant and local tsunamis.
  - USGS Report to the NRC states the following concerning landslides in the Gulf of Mexico:
    (*USGS, 2008. "Evaluation of Tsunami Sources with the Potential to Impact the U.S. Atlantic and Gulf Coasts," by the Atlantic and Gulf of Mexico Tsunami Hazard Assessment Group)*.
    - Large landslides were probably active before 7500 years ago.
    - Active landslides are small and may not pose a tsunami hazard.

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LNP PMT Analysis is Conservative because…

- The five step formulaic approach is a bounding analysis based on the results of many comprehensive numerical simulations by Ward and others.
- Site-specific conditions are included in many of the formula parameters.
  - The most site-specific approach for run-in includes final equations that include the non-linear profile between the shoreline and the LNP site.
- Conservatism is included in every step of the process through parameter selection and bounding formulae.
  - Potential maximum Gulf of Mexico landslides that were considered are extremely conservative because of their size and old age.

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LNP PMT Conclusions

- Earthquake derived PMTs are much smaller than PMTs created by landslides (<2x).
- The worst case Mississippi Breaks landslide (perhaps a 1 in 10,000 year event) generates the highest PMT run-up at EL 20.1 ft. NAVD88.
  - The highest PMT run-up is about 30 feet below the LNP site, even considering sea level rise and anomalies.
- By literature and this bounding analysis, the LNP site will not be impacted by an PMT.
- Therefore, there is no safety-related tsunami hazard at the LNP site.

Florida Tsunami Flooding Review of the Levy County Units 1 and 2 COLA

Questions?

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